Challenges in magnet design for SPring-8-II

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on behalf of

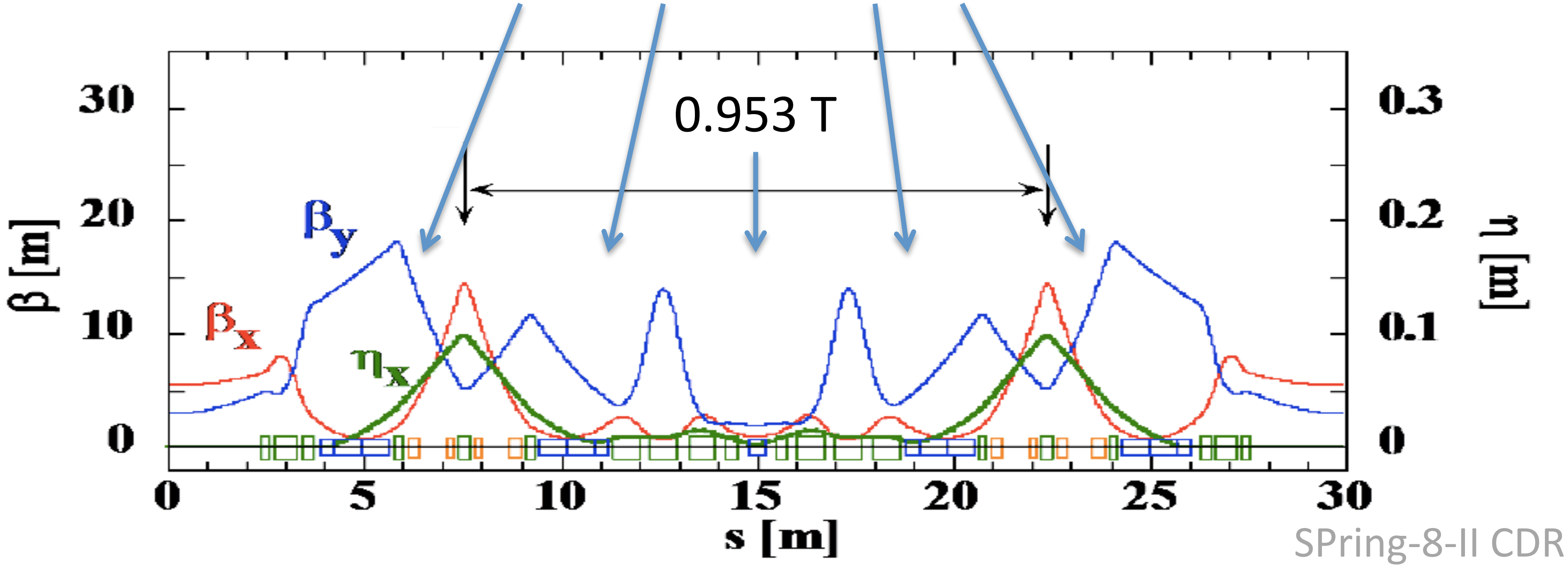
SPring-8 upgrade working group

Special thanks: <u>SPring-8-II magnet team</u>

Fukami, Taniuchi, Takano, Aoki, Mitsuda, Hara

SPring-8-II 5 bend lattice

Longitudinal gradient bend（B=0.58, 0.30, 0.17 T & 0.78, 0.40, 0.22 T）



SPring-8-II CDR

Magnets	mags / cell	Total
Normal bend	1	44
Longitudinal gradient bend	4	176
Quadrupole	20	880
Sextupole	8	352
Octupole	3	132

Requirements (tentative)

- Max field: B = 0.953 [T]、Q = 56 [T/m]、SX = 2,620 [T/m^2]
- Bore diameter: 25 mm@B、34 mm@Q&SX
- Field accuracy (BL, GL): $\sigma < 5 \times 10^{-4}$
- Alignment: $\sigma < 25$ [μm] on girder, 75 [μm] between girders
- Shutdown time: 1 year
- Power consumption

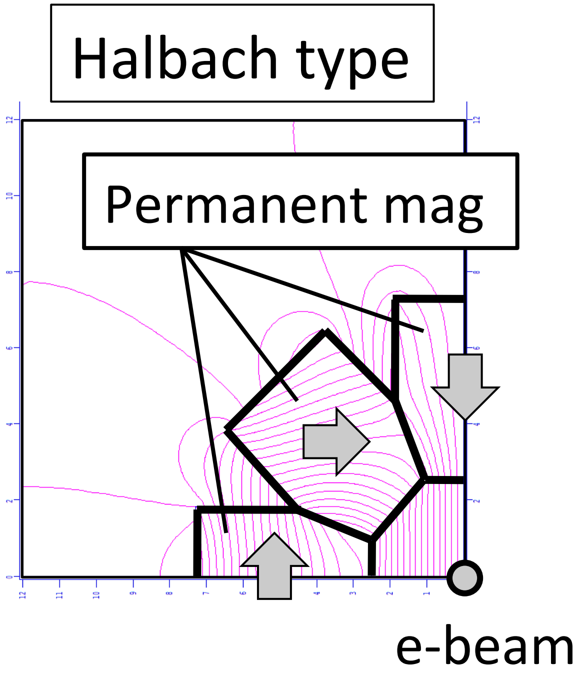
Features

- Low field gradient -> Existing technologies for Q, SX, Oct.
- Permanent magnet

Permanent Magnet

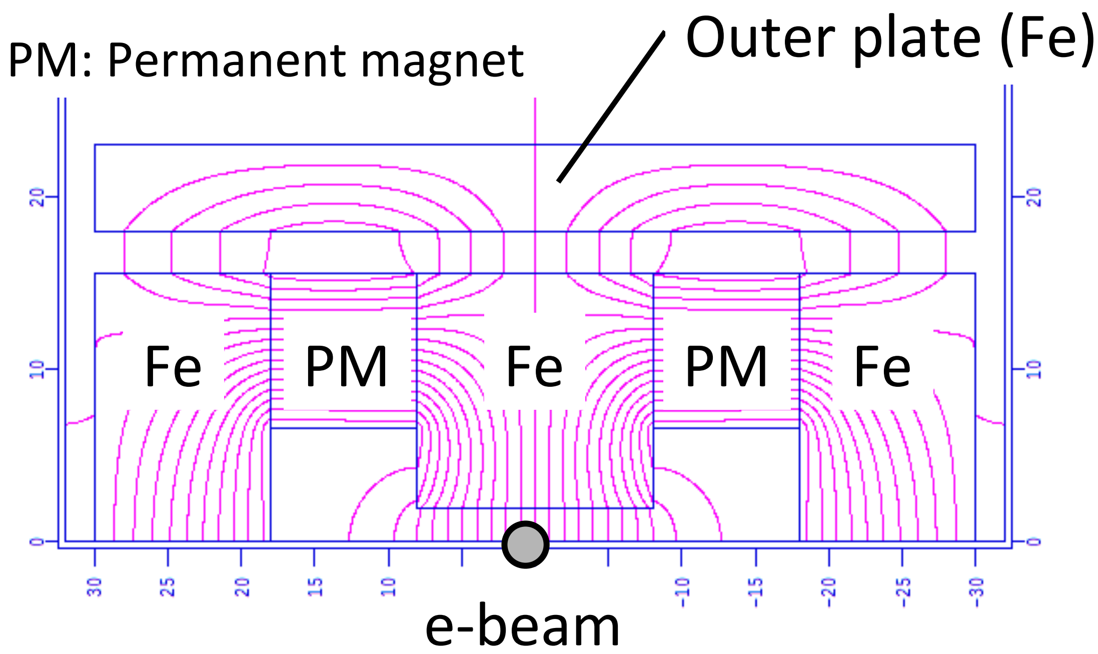
Pros:
- No electric power (cf. SP8 dipoles ~ $1M/year)
- No power supply failure/no power supply maintenance
- No water vibration

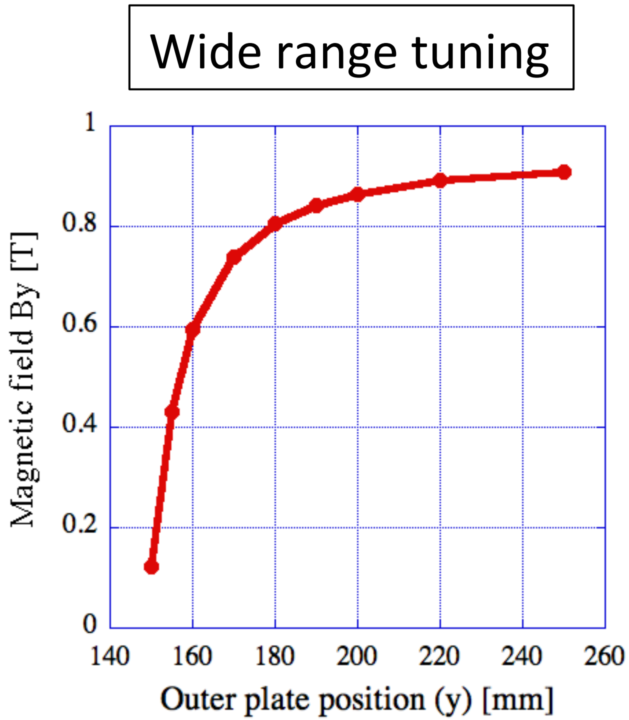
Cons:
- Magnetic field tuning
- Inhomogeneous field distribution
  due to imperfection of magnetization
- Demagnetization due to radiation*
- Fringe field
- Temperature coefficient of remanence



cf. J. Chavanne, IPAC2014 talk and today's talk.
Several conference papers by SIRIUS.
* Bizen et al., NIM A 467 (2001) 185.

Magnetic field tuning for hybrid-type permanent magnet





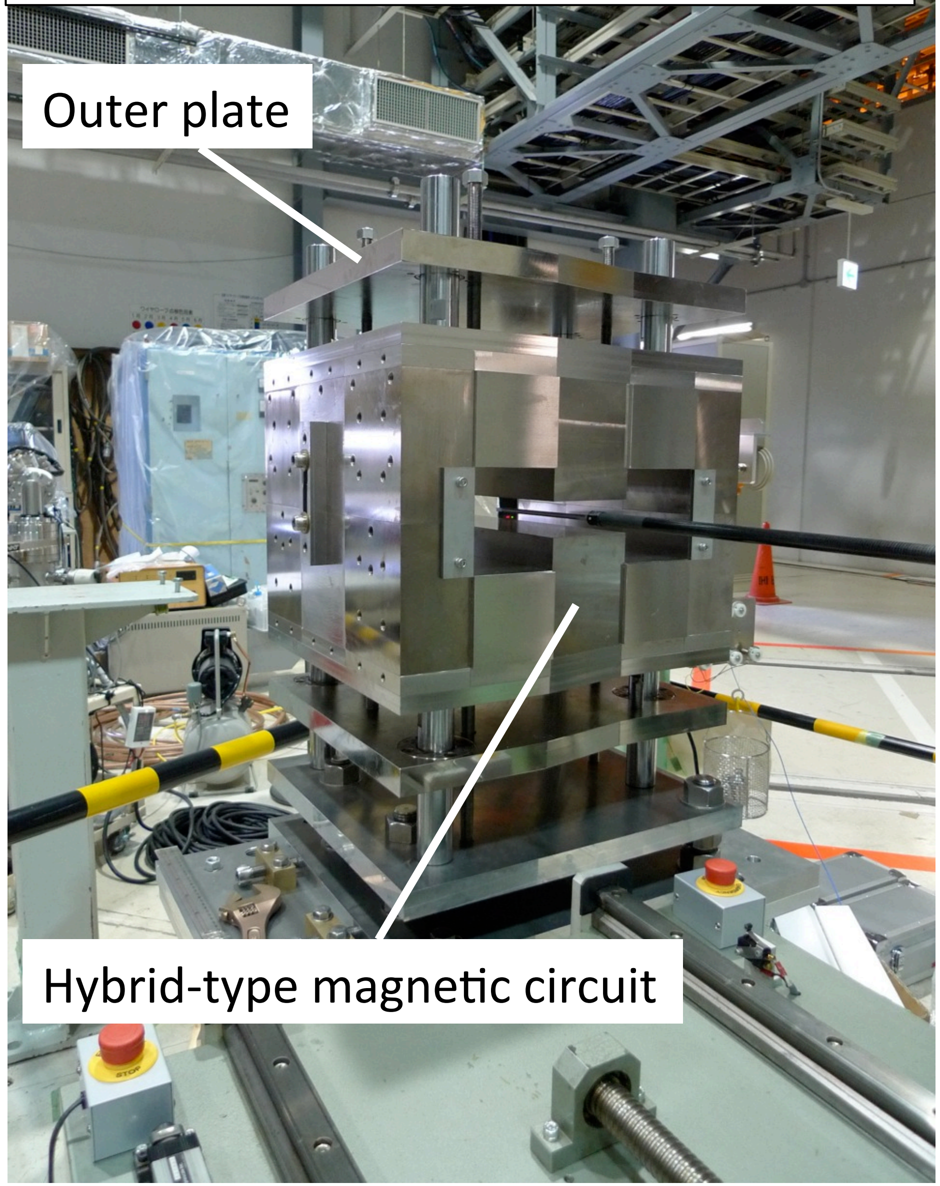
$$\int_{gap} B \cdot ds + \frac{1}{\mu_r} \int_{Iron} B \cdot ds = \mu_0 I$$

$$\left(B \text{ on beam axis} \right) = \Phi_{gap} / S_{gap} = \left(\Phi_{total} - \Phi_{OP} \right) / S_{gap}$$

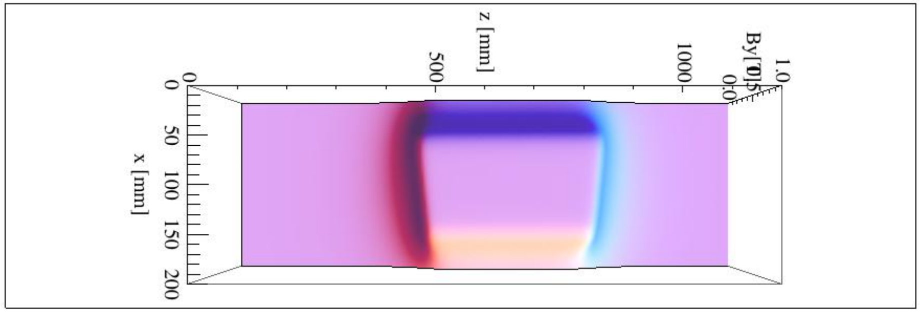
For permanent magnet, flux density B can be adjusted by changing outer plate positions.

T. Watanabe et al., Proc. of IPAC'14.

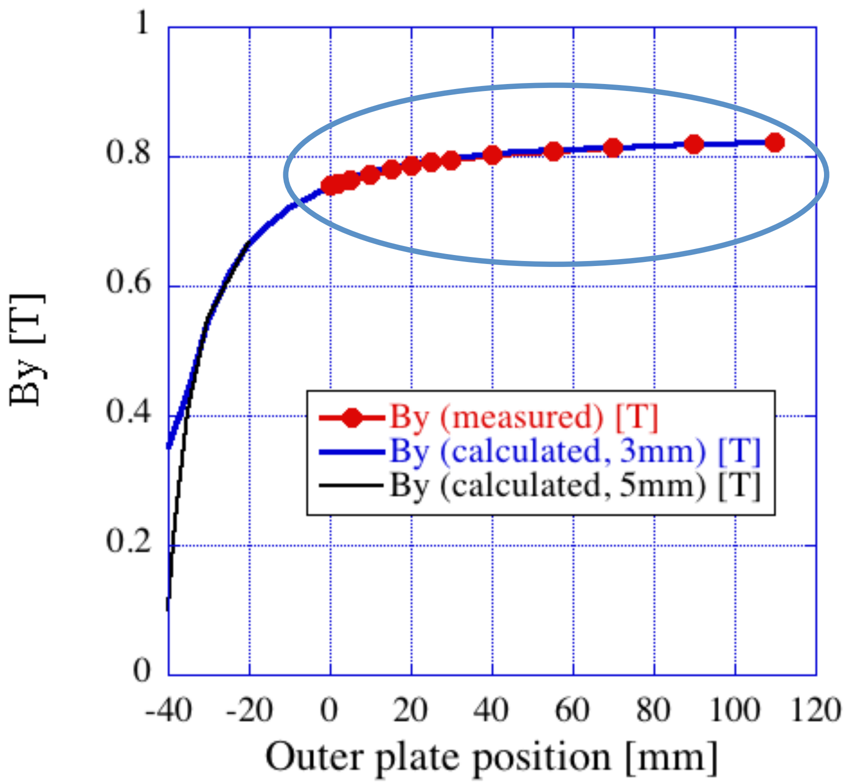
Dipole magnet with variable field



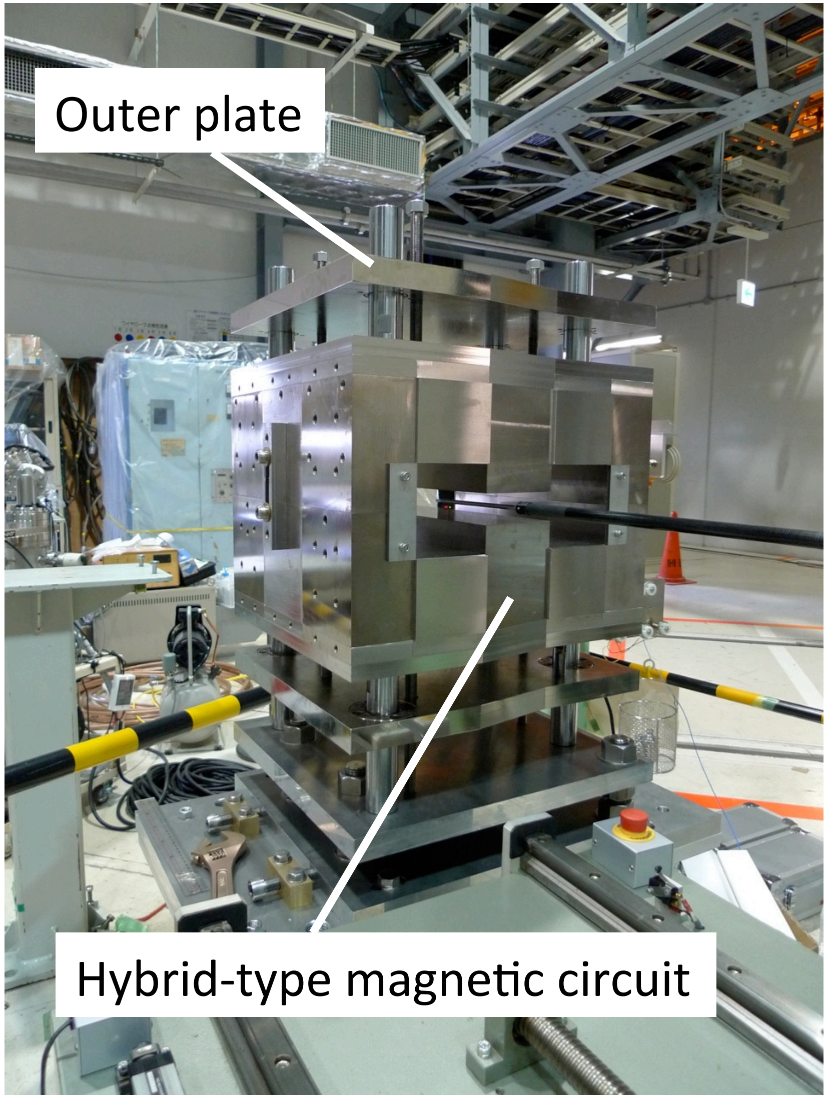
Measured result of magnetic field mapping



Measured result of magnetic field tuning



Dipole magnet with variable field



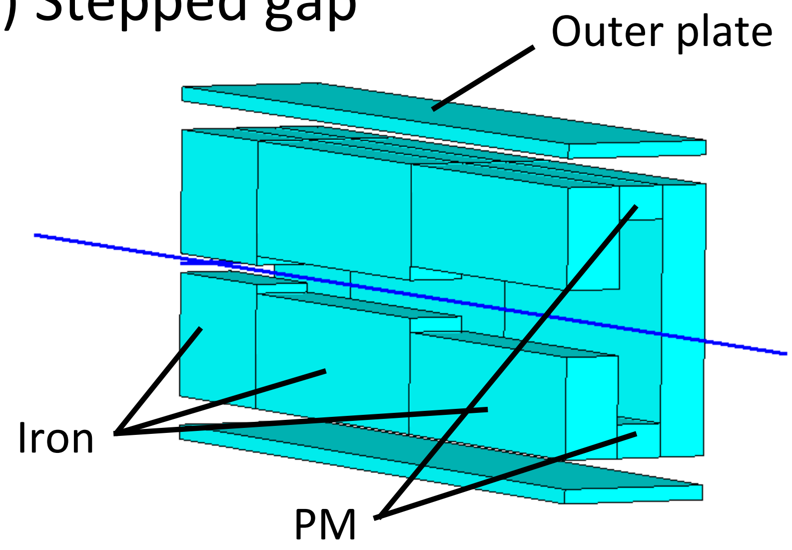
- ☑ Hybrid PM with some volume
- ☑ Homogeneous magnetic field distribution
- ☑ Magnetic field tuning by outer plates
- ☑ Radiation damage (will be further studied)
- ☑ Cost

- ☐ C-shaped structure with precise mechanics*
- ☐ Longitudinal field gradient
- ☐ Fringe field
- ☐ Temperature coefficient of remanence [-0.1 %/K]

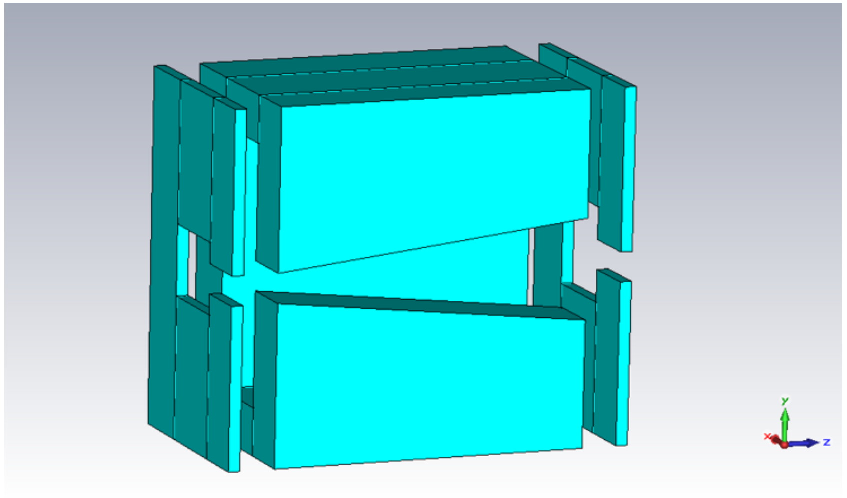
* Mechanical gradient of gap ~ 70 um

Recipes for longitudinal gradient bend

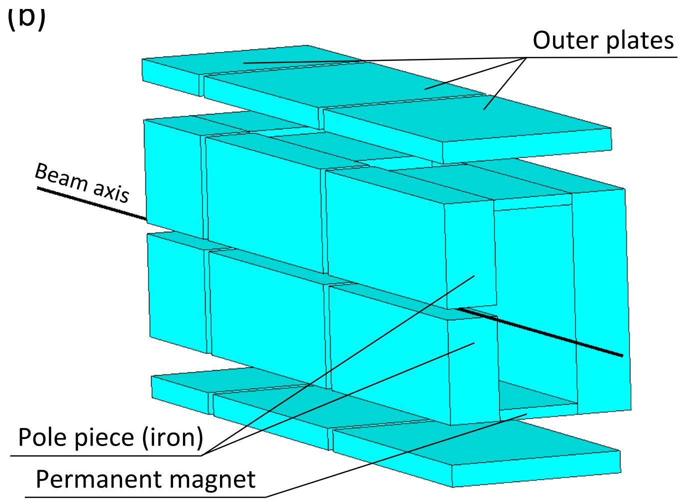
(A) Stepped gap



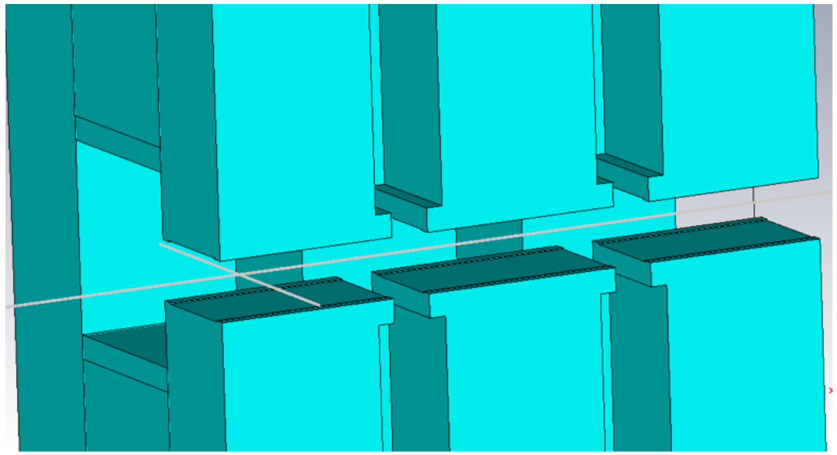
(B) Smooth gradient



(C) Const. gap with spacing

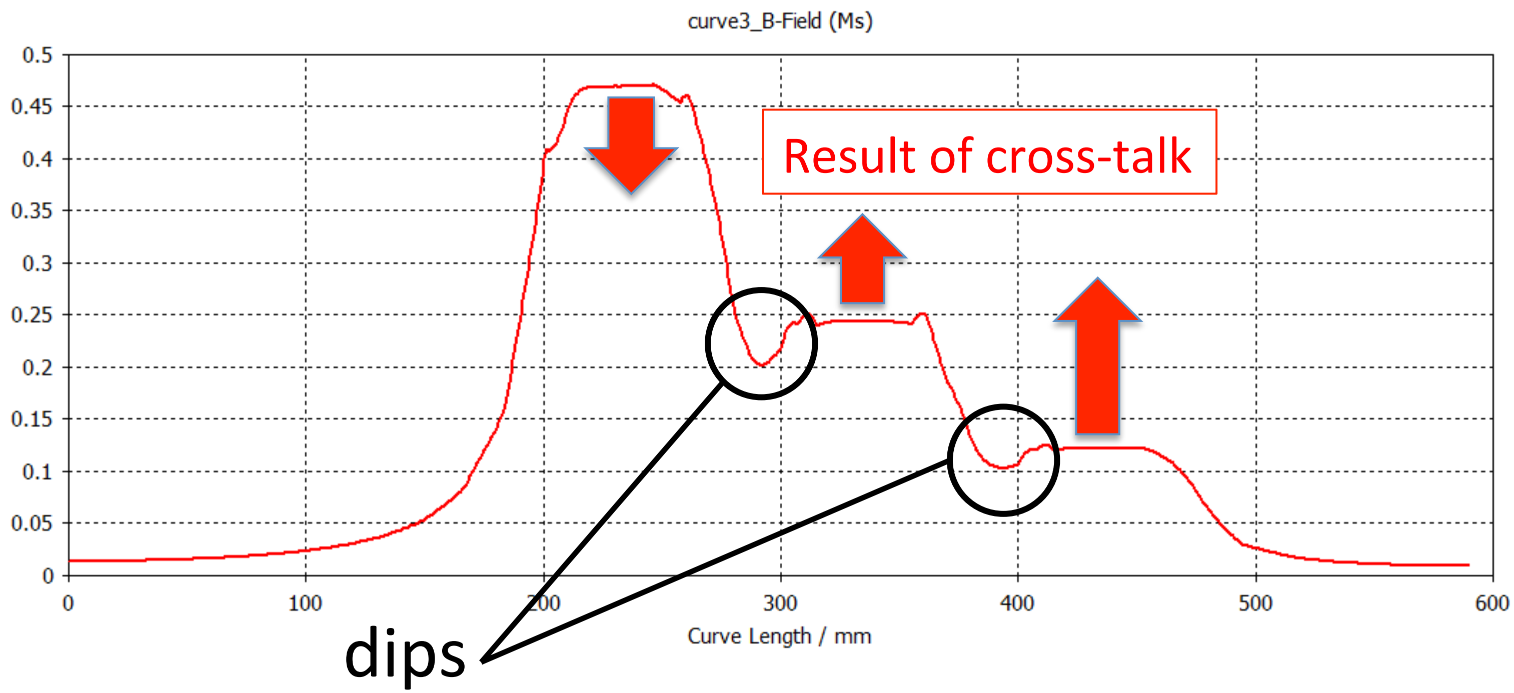


(D) Spacing + Nose structure



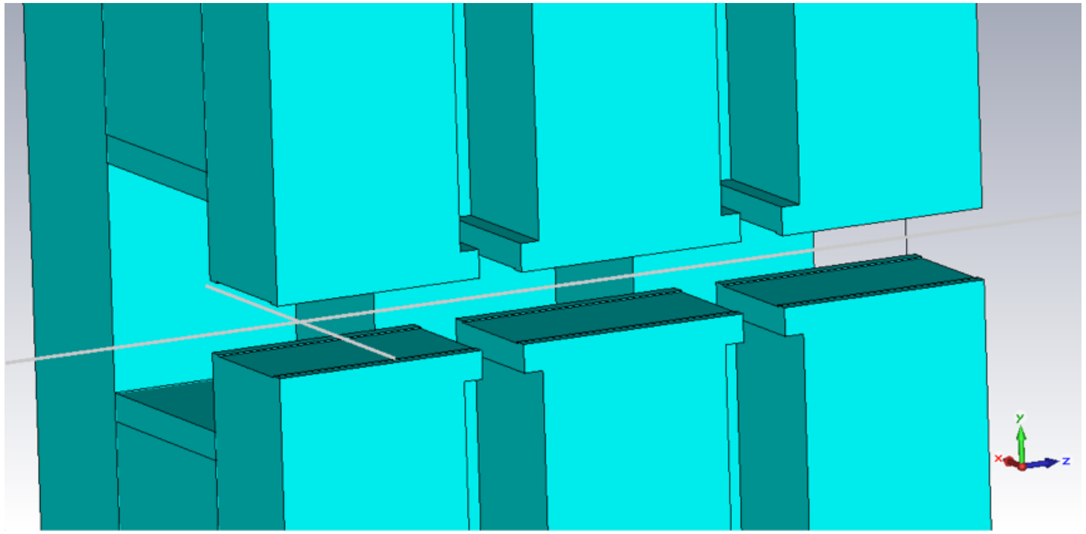
Trade-off between "dips" and "cross-talk" between segments

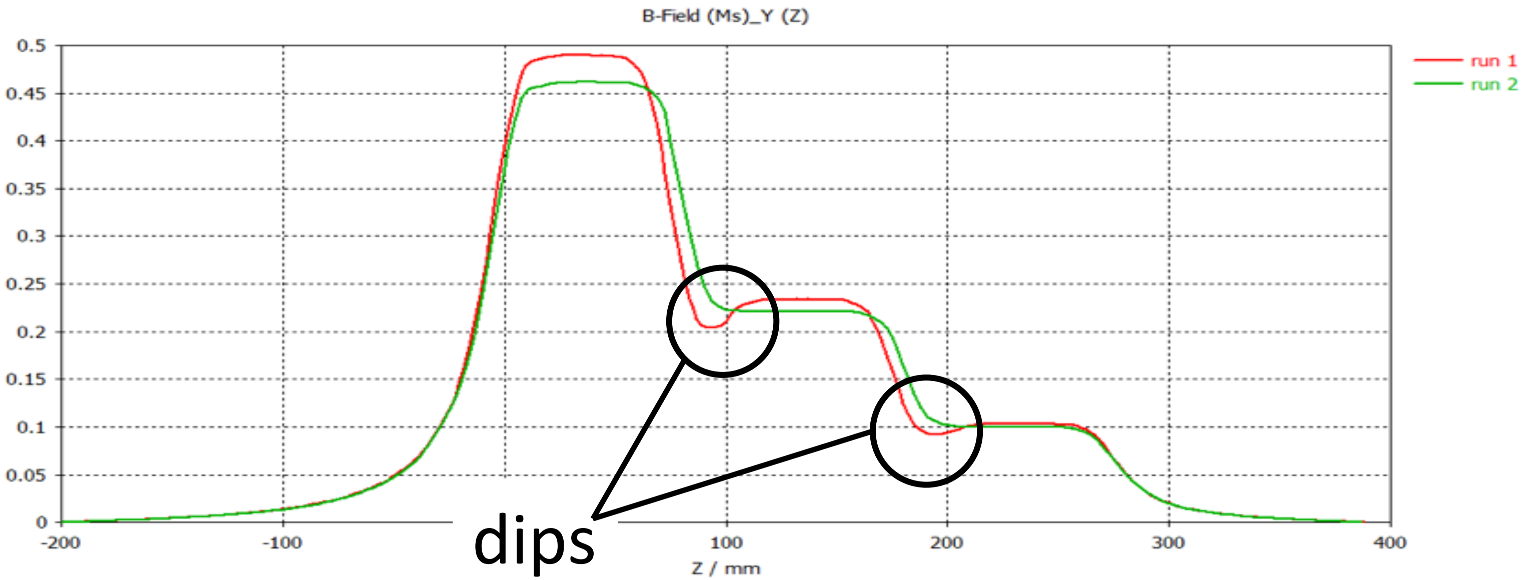
Distance bet. Seg.	Dips	Cross talk
Small	Small (good)	Large (bad)
Large	Large (bad)	Small (good)



We may luckily find a good compromise, but there may be another way...

Nose structure works for reducing "dips", while keeping cross-talk small.

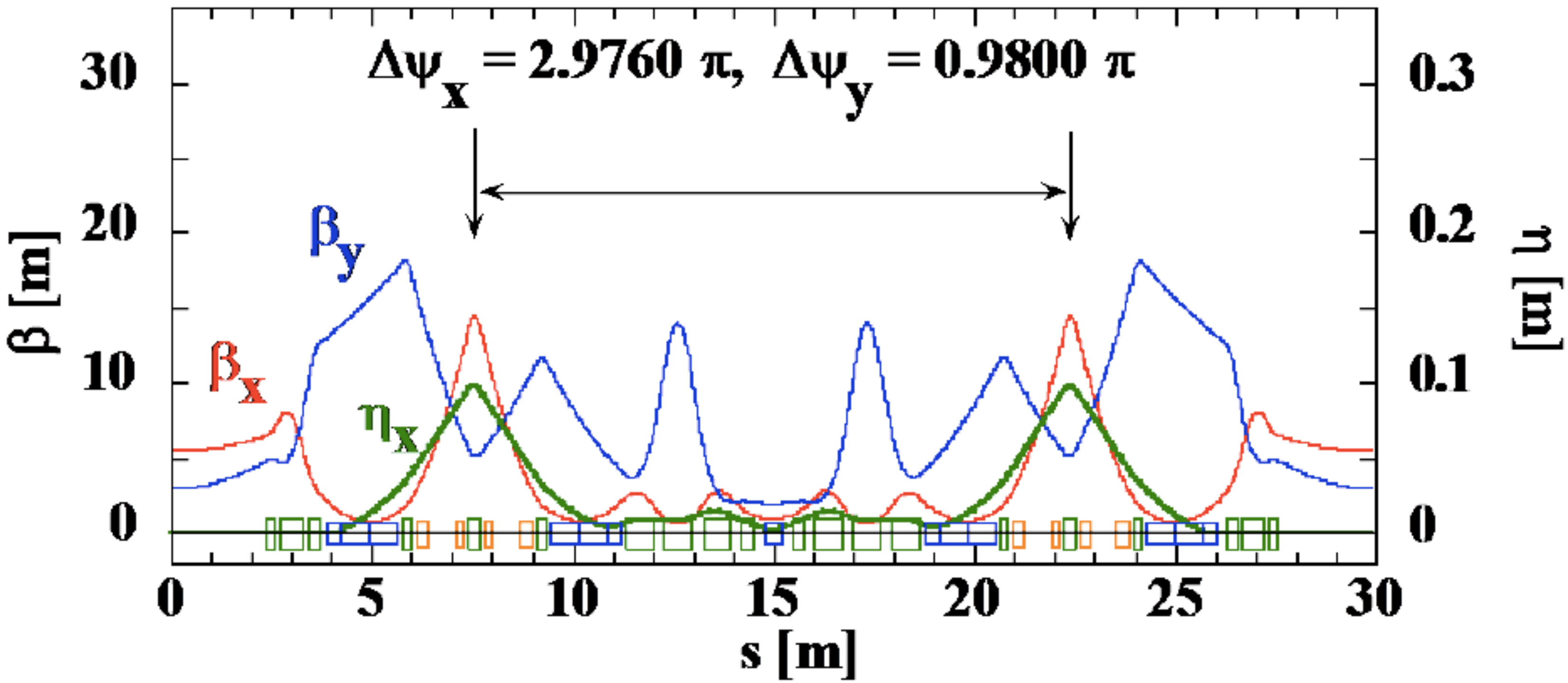




Fringe field

Low emittance ring → High packing factor

generally



SPring-8-II CDR

Acceptable: overlap of fringe fields

Not acceptable: fringe field penetrates into next magnet

Challenges for SPring-8-II longitudinal gradient bend

☑ Hybrid PM with some volume

☑ Homogeneous magnetic field distribution

☑ Magnetic field tuning by outer plates

☑ Radiation damage (will be further studied)

☑ Cost

☒ C-shaped structure with precise mechanics

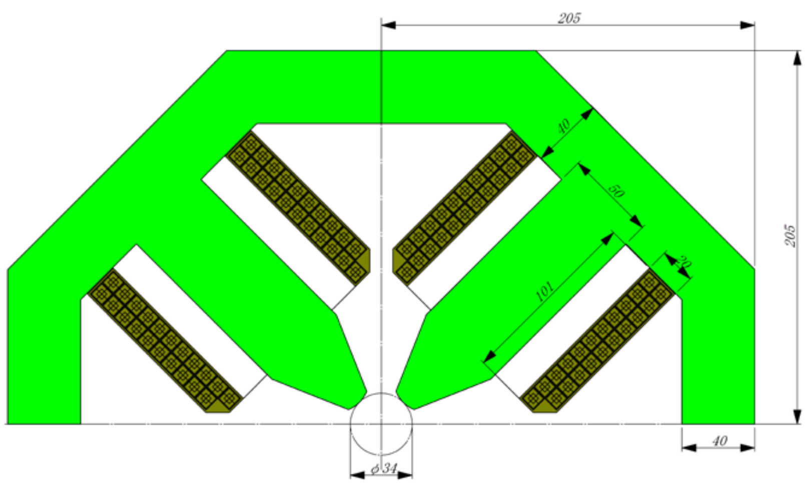
☒ Longitudinal field gradient

☐ Fringe field ➡ Almost done

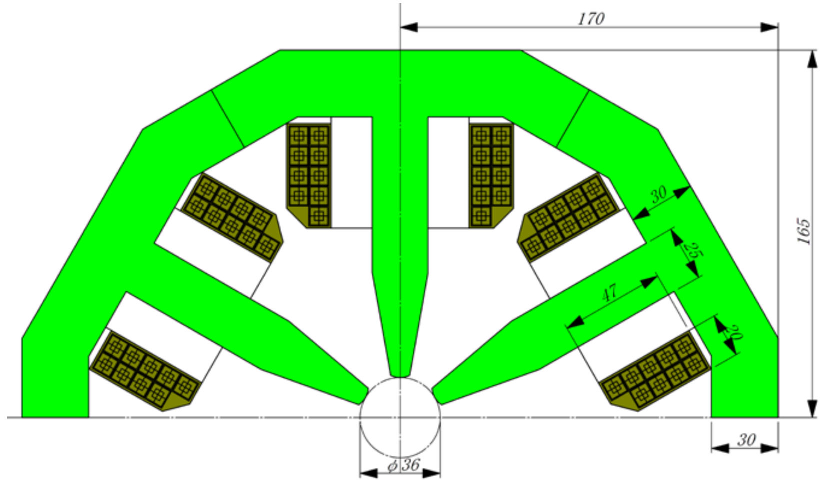
☐ Temperature coefficient of remanence ➡ Almost done

New test magnet is coming soon.

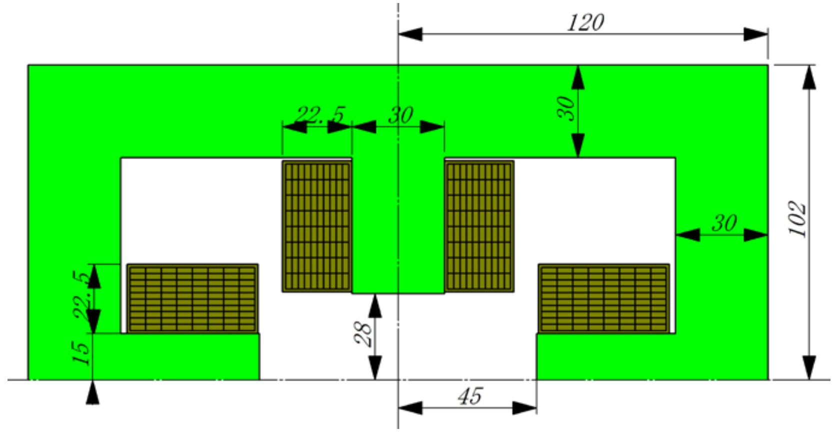
Quadrupole magnet



Sextupole magnet



Steering magnet



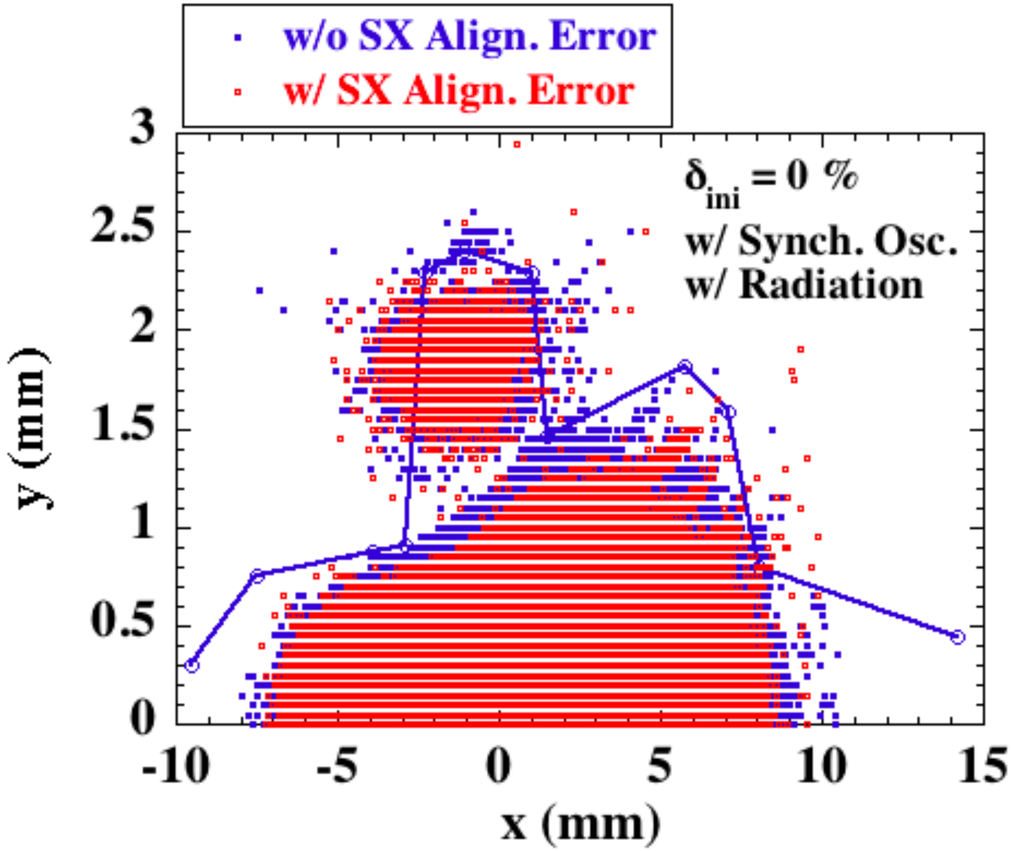
SPring-8-II CDR

Further modification on going:

Compact: low manufacturing cost, light weight, good stability

Large : low running cost, less interference with light

Magnet alignment is critical for next generation light sources

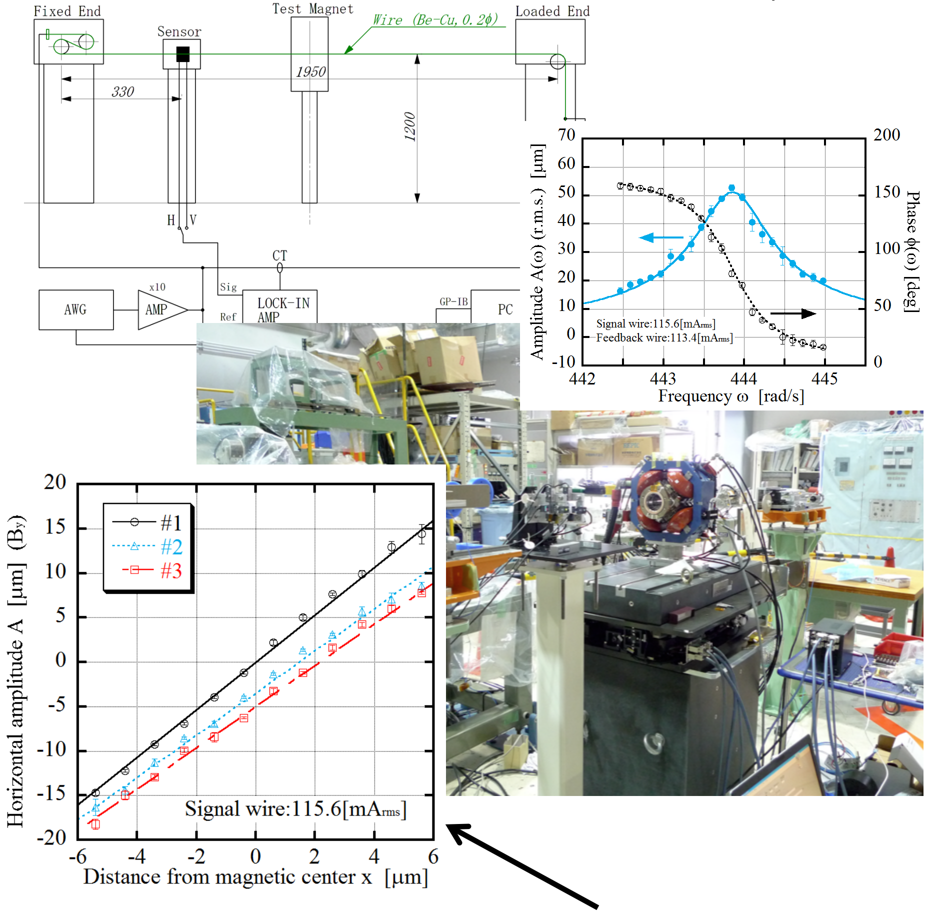


SPring-8-II CDR

Dynamic aperture shrinks due to magnet alignment errors.
For us, ~25um precision is necessary for SPring-8-II.

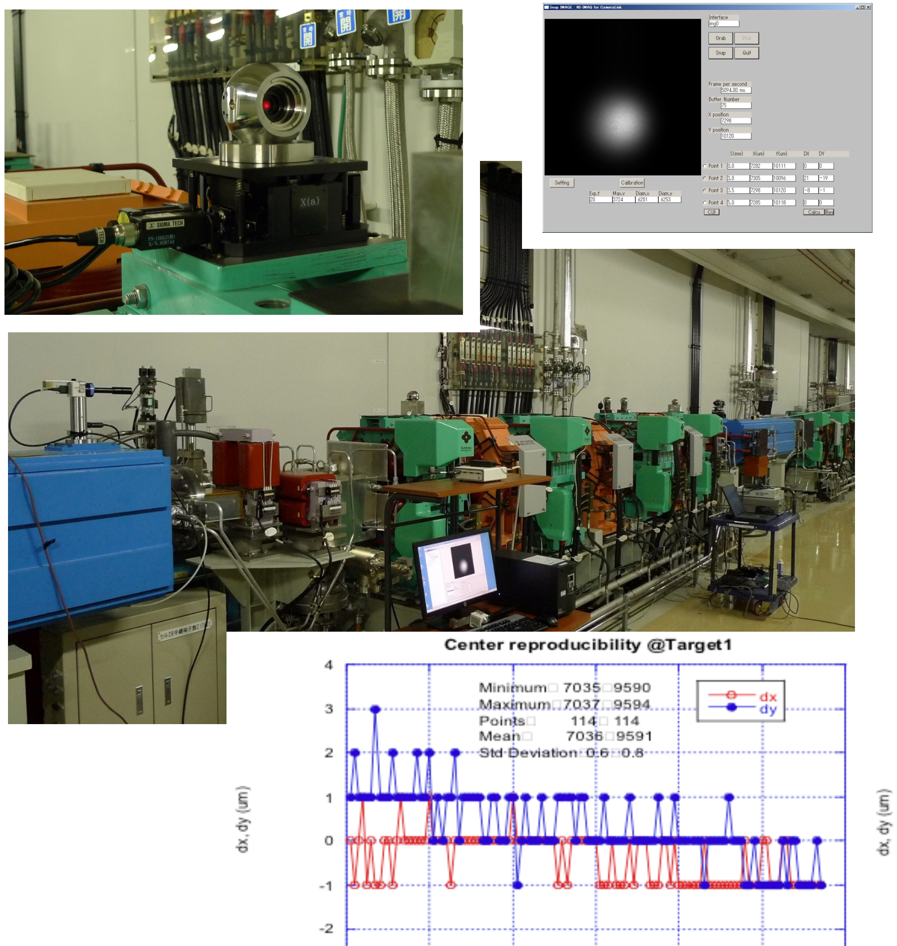
Vibrating wire method

A. Jain, NSLS-II



A wire resolves sub-μm shift of magnet position.

Iris diaphragm laser alignment



$\Delta = 2 + 2\sqrt{(0.7^2+2^2+1.5^2)}=7$ (μm)

Key issues:
- 1-year shutdown
- Long term stability (temp, girder deformation, etc.)

Summary

- SPring-8 has discussed and tested permanent magnet for future light sources.

  - Go green, go ultimate -

- New magnet with variable magnetic field, small fringes, and homogeneous distribution has been designed and tested.

- Electromagnets for Q, SX, Oct are assumed to be available by existing technologies.

- Precise alignment is also a key issue: under development.

How far we can achieve for future light sources will be much affected by magnet designs (and new ideas).
It is worth challenging new magnet designs to push the limit and open new possibilities of future light sources.